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GAMMA-GAMMA ANGULAR CORRELATION
IN THE DECAY OF COBALT-60
BURTON J. CONWAY

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IN THE DECAY OF COBALT 60

BURTON J. CONWAY

GAMMA-GAMMA ANGULAR CORRELATION
IN THE DECAY OF COBALT-60

by
BURTON J. CONWAY
CAPTAIN, UNITED STATES ARMY

Submitted in partial fulfillment of
the requirements for the degree of
MASTER OF SCIENCE
IN
PHYSICS

UNITED STATES NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

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thesis
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from the

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ABSTRACT

This is a continuation of the work of assembling and testing the equipment necessary to conduct gamma-gamma angular correlation experiments, started by Fort A. Verser, Jr. at the US Naval Post-graduate School (1).

No substantial changes were made in the equipment, but rather a rerun of the Cobalt-60 experiment was made to confirm the results obtained in the previous work. A comparison of the previous work confirms that there is a definite distortion in the shape of the observed correlation function.

The statistical analysis of the data and the solid angle corrections required for evaluation of the results have been programmed for calculation by use of the 1604 Digital Computer. This paper outlines these programs in detail.

The author wishes to express his appreciation for the assistance given him by Professor Harry E. Handler and for his guidance throughout this investigation. Appreciation is expressed to Professor Edmund A. Milne for his advice and comments. Captain T. R. Abernathy, USMC, was very helpful in providing valuable assistance and discussions on various aspects of the computer programming. The cooperation and assistance of Mr. Mervyn C. Brillhart in maintaining and testing the electronic equipment was indispensable.

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CHAPTER I

INTRODUCTION

The decay of Cobalt-60 to an excited state of Nickel-60 and the angular correlation of the resulting gamma-gamma cascade have been studied extensively experimentally (2,6,8,9, and others) and the results of the correlation measurements agree very well with the theoretical correlation for the decay scheme shown in Figure 1. Consequently, the decay of Cobalt-60 is now used as one standard for the testing of correlation equipment.

Angular correlation equipment was assembled at the US Naval Postgraduate School by Verser in 1960 for the investigation of the properties of low-lying excited nuclear states. His testing of the operating characteristics of the equipment by the angular correlation of the cascading gamma rays resulting from the decay of Cobalt-60 yielded an observed correlation curve whose shape was not in agreement with the theoretical curve. This work was initiated in order to attempt to verify Verser's results.

In order to facilitate the statistical analysis of the data, a program has been worked out for the use of the 1604 Digital Computer. The program follows the procedures outlined by M.E. Rose (2) and is contained completely in Appendix I.

An additional program has been written to compute the solid angle corrections, which must be applied to the theoretical curve, by the method of M.E. Rose (2). This program is outlined in Appendix II.

The results of this work agreed within statistical expectation with those obtained by Verser, indicating that the unexpected shape of the curve is apparently real and not an instrumental effect. These results are given in Chapter VI.

PARTIAL DECAY SCHEME OF COBALT-60

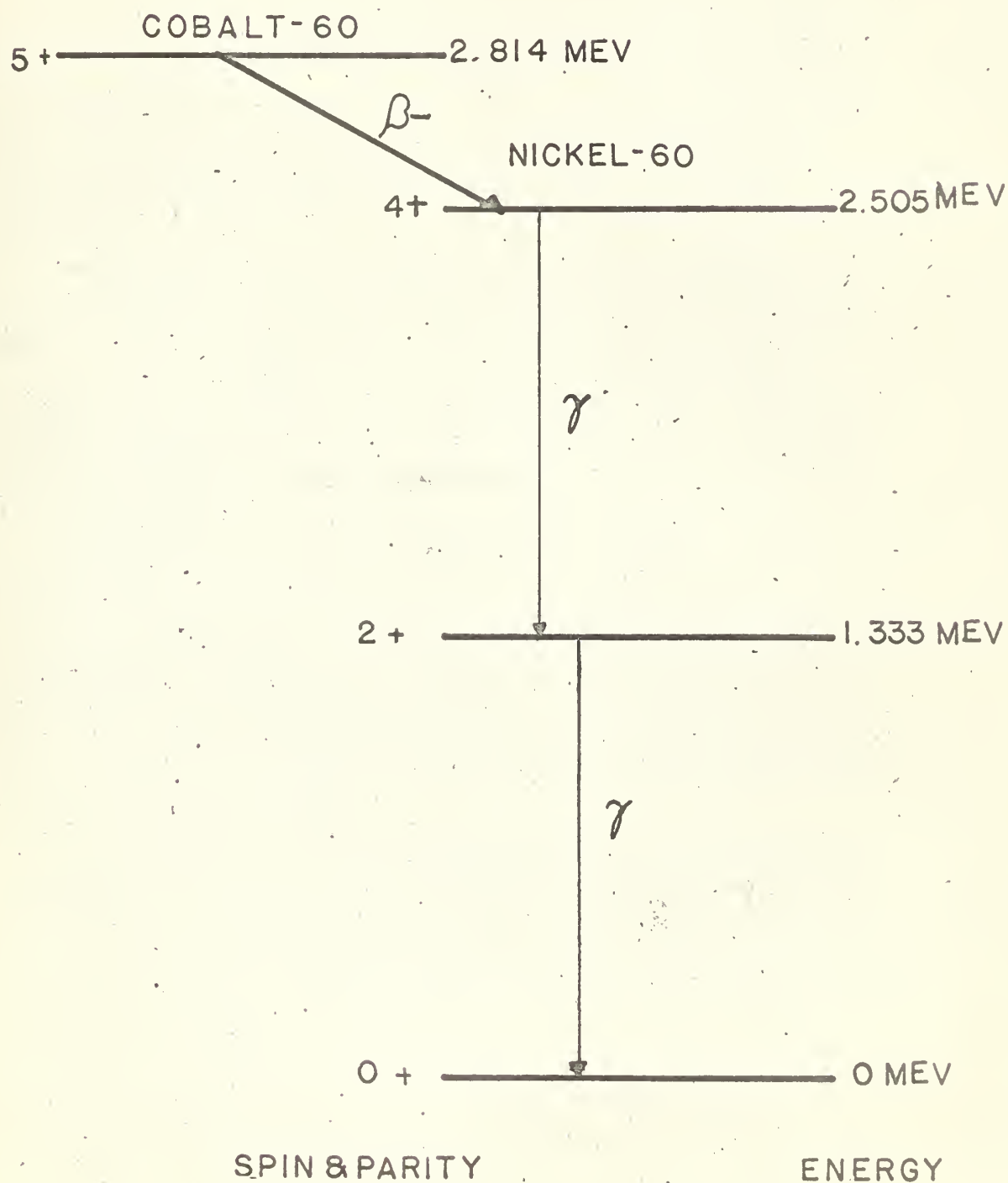


FIGURE 1 2

CHAPTER II

THEORETICAL CONSIDERATIONS

The determination of the angular momentum quantum numbers, or spins, of low-lying short-lived excited nuclear states by the nuclear spectroscopic tool, known as angular correlation of successively emitted radiations, is quite common practice today. Only within recent years, because of the vast advancement of electronics, has practical utilization of this tool become possible.

Since nuclei, under ordinary conditions, are randomly oriented in space, it is not possible to observe a radiation pattern. This is due to the fact that the probability of emission of a radiation by an excited nucleus, depends on the angle between the nuclear spin axis and the direction of the emission. Therefore, in order to observe a radiation pattern, it is first necessary to orient the nuclei.

One method of orienting certain nuclei consists of placing the sample in an electric field gradient or a strong magnetic field at a very low temperature. Another method, the one used in the present consideration, consists of selecting nuclei whose nuclear states have spins lying in preferred directions. This happens to be the case for the intermediate state if a nucleus decays by successive emission of two radiations.

In an angular correlation experiment the first radiation is observed in a fixed direction. This establishes an axis to which the direction of emission of the second radiation, originating from the state formed by the first, can be referred. The second radiation has preferred angles of emission with respect to the direction of the first.

In order that the correlation exhibit maximum anisotropy, the angular momentum vector of the intermediate state must not change

direction significantly before the second radiation occurs. The mean life of the intermediate state must be less than about 10^{-8} seconds, the typical precession period of the nuclear spin about local perturbing fields. The angular correlation function is determined by the nature of the radiations and by the spins of the states involved, and thus its measurement may lead to an unambiguous choice of spins for the states.

The theoretical expressions for the correlation functions have been worked out for a large number of cases of interest (7). For the particular case of a gamma-gamma cascade, the correlation function $W(\theta)$ is

$$W(\theta) = \sum_{n=0}^{n_{\max}} A_n P_n(\cos \theta) = \sum_{n=0}^{n_{\max}} B_n \cos^n \theta \quad (1)$$

where P_n is the Legendre Polynomial of even order n , $n_{\max}$ is the smallest even integer of the set of three numbers consisting of twice the multipole order of each of the two gamma rays, and θ is the angle between the directions of emission of the two gamma rays.

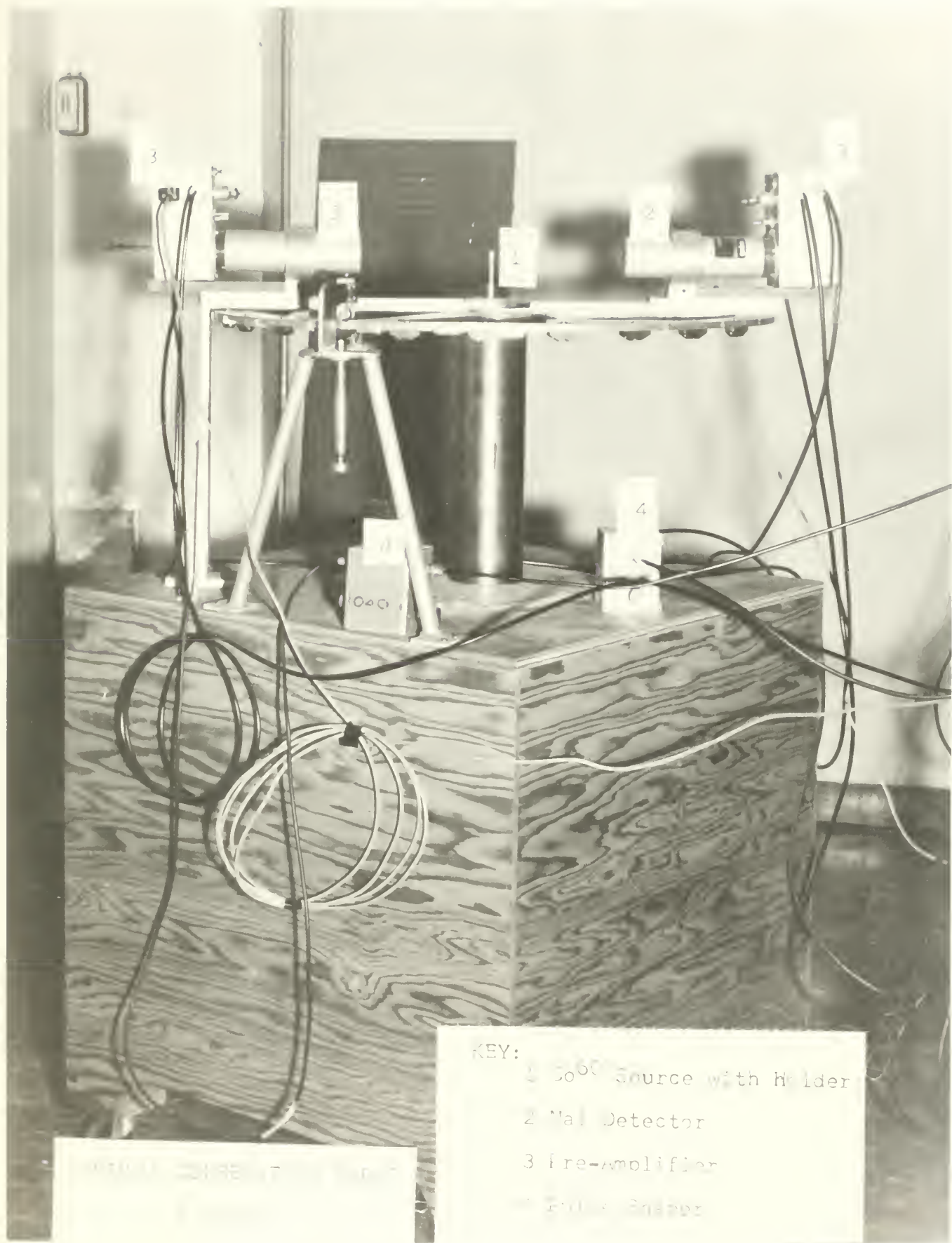
The theoretical correlation function for the cascade in Nickel-60, assuming point detectors and a point source, is

$$W(\theta) = 1 + 0.1020 P_2(\cos \theta) + 0.0091 P_4(\cos \theta) \quad (2)$$

with an anisotropy

$$R = \frac{W(180^\circ) - W(90^\circ)}{W(90^\circ)} = 0.1667 \quad (3)$$

Many workers, after correcting these theoretical results for the effect of non-point detectors have found good agreement between them and their experimental correlation results.



KEY:

1 Co⁶⁰ Source with Holder

2 NaI Detector

3 Pre-amplifier

4 Pulse Generator

CHAPTER III

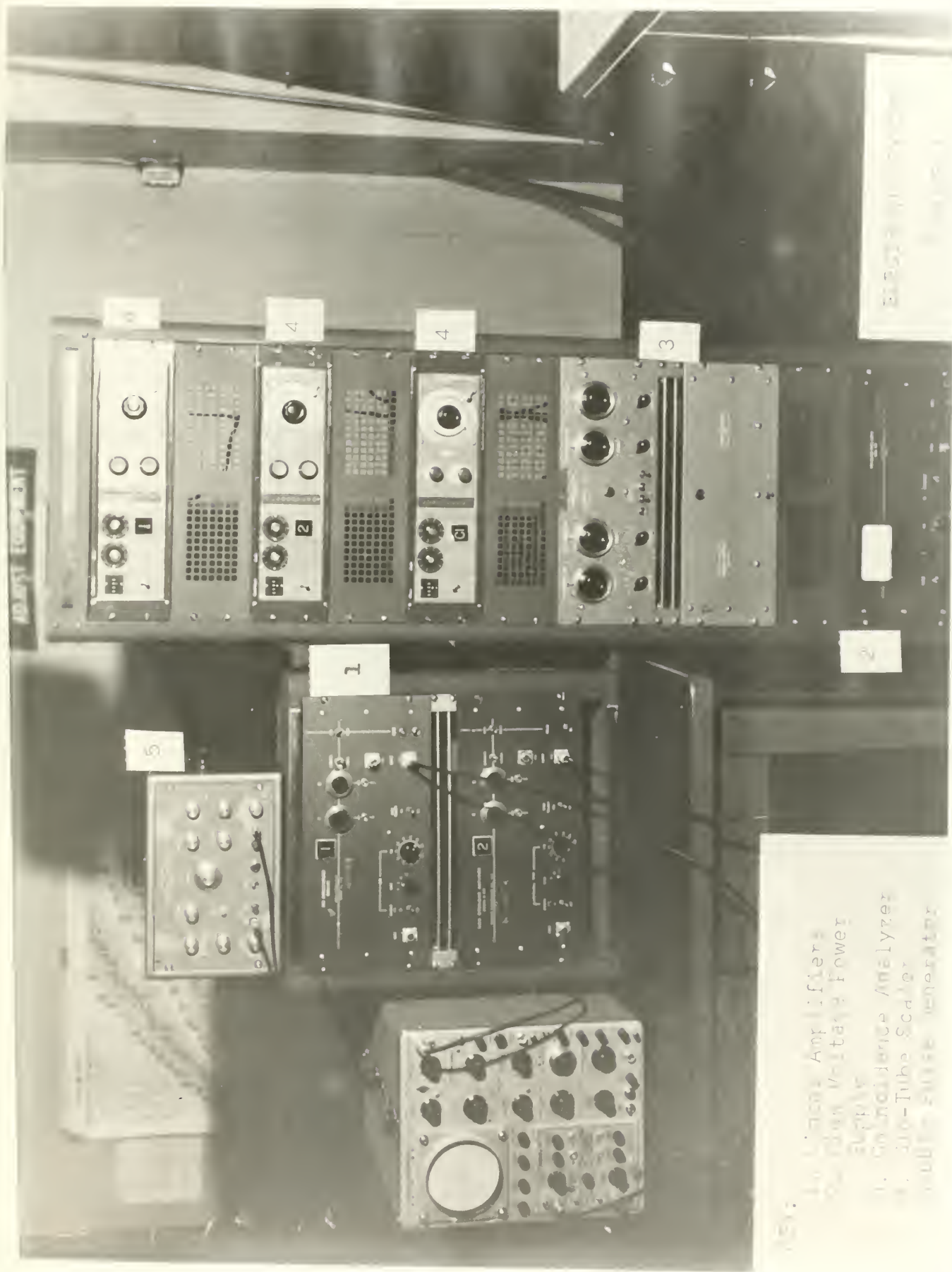
DESCRIPTION OF EQUIPMENT

The equipment needed for the gamma-gamma correlation measurements must furnish means for detecting the radiation, pulse-height amplification with selection or discrimination, coincidence analysis, and adequate recording of the counts in the various counting channels. A mechanical system must also be provided for mounting the detectors and changing their relative positions and for holding and positioning the radioactive source.

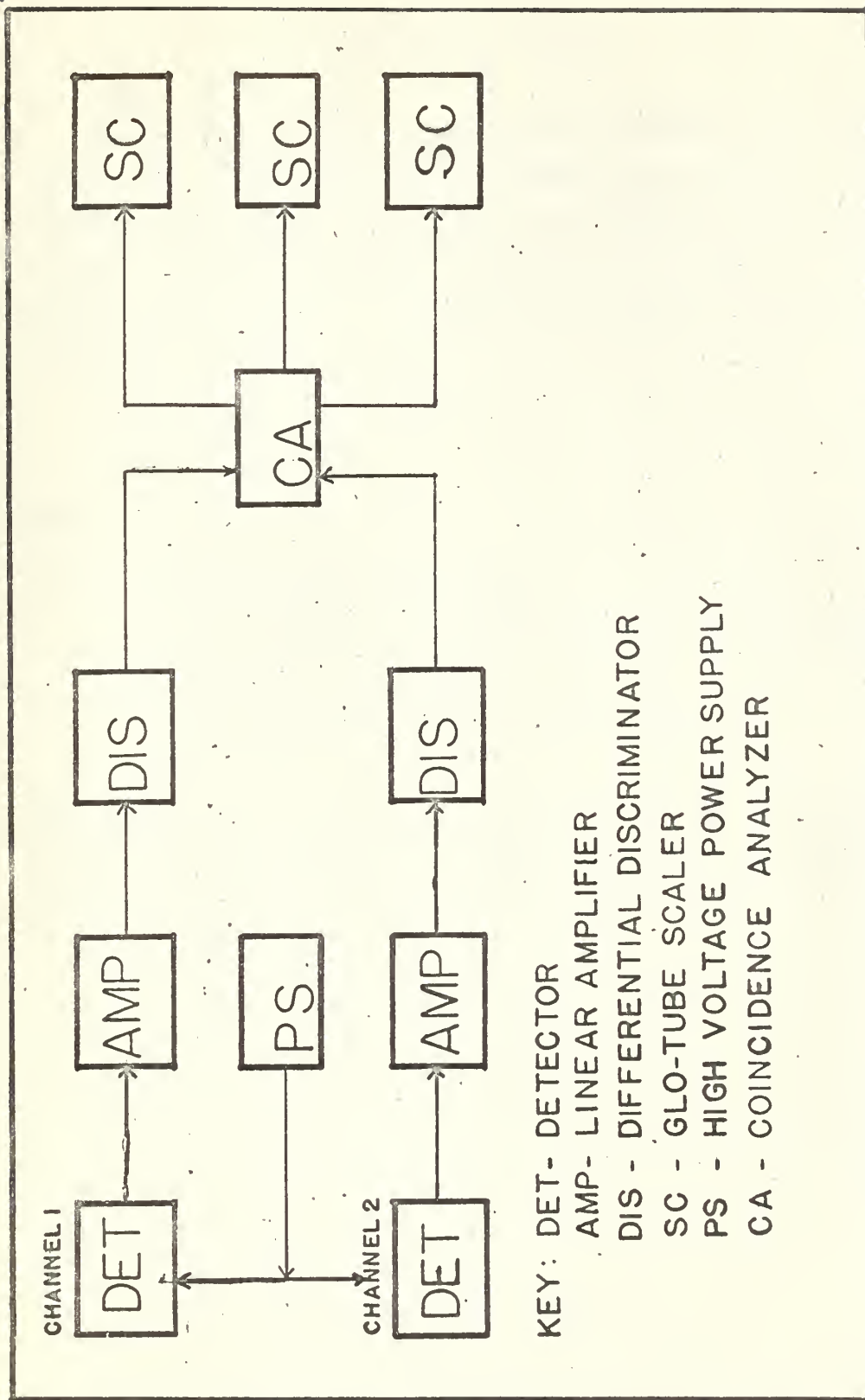
The apparatus used for this work was that assembled by Verser and described in detail in his report. Therefore, only a brief description of the equipment and of the minor alterations performed on it will be presented.

Figure 2 is a photograph of the mechanical setup. The original base of the correlation table has been replaced, the new base is of solid brass with a bearing mounted shaft to enable accurate manual detector positioning.

The electronic equipment (Figure 3) has the functions of detection of the radiation, pulse-height amplification and discrimination, coincidence analysis, and recording the number of counts. The only change in the electronic equipment was in the pulse-shaping networks used in the initial calibration of the apparatus. The pulse shapers were rebuilt to give a better simulation between the test pulses and the actual pulses encountered under operating conditions.



1. Coincidence Analyzer
 2. 30-Tube Scaler
 3. Pulse-Height Generator
 4. Linear Amplifier
 5. 60-Hz Voltage Power Supply



SCHEMATIC DIAGRAM OF THE ELECTRONIC SYSTEM

FIGURE 4

CHAPTER IV

EXPERIMENTAL ANALYSIS

The angular correlation function $W(\theta)$ (Equation 1) must be expressed in terms of experimentally-observable quantities. The equipment records the total number of coincidences as a function of the angle between the detectors, and the total number of radiations captured in each channel. C_t , the total number of coincidences in a counting period, is given by

$$C_t = C_g + C_a + C_b \quad (4)$$

where

C_g = the number of genuine coincidences due to the two cascading radiations,

C_a = the number of accidental coincidences due to the finite resolving time of the electronic equipment, and

C_b = the number of background coincidences.

The half-life of the source is long compared to the time required to collect the necessary data; therefore, equation (4) can be rearranged and rewritten in terms of counting rates:

$$\dot{C}_g = \dot{C}_t - \dot{C}_a - \dot{C}_b \quad (5)$$

$\dot{C}_g$ can also be expressed in terms of other parameters:

$$\dot{C}_g = (\epsilon_{11}\alpha_{11}\rho_{11}\alpha_{22}\rho_{22} + \epsilon_{12}\alpha_{12}\rho_{12}\epsilon_{21}\alpha_{21}\rho_{21})N_0\theta_{12}\overline{W}(\theta_1) \quad (6)$$

where

N_0 = the absolute source strength

θ_{jk} = the fraction of nuclei decaying by the emission of gamma ray "j" and gamma ray "k" in a cascade

Ω_i = the fractional solid angle subtended by the crystal in Channel "i"

ρ_{ij} = the fraction of gamma rays "j" which leave the source in the right direction to enter crystal "i" that are not absorbed before reaching the crystal

ϵ_{ij} = the total efficiency of the crystal in Channel "i" for gamma ray "j"

α_{ij} = the fraction of the number of gamma rays "j" captured by the crystal in Channel "i" whose pulse heights are accepted by the energy discrimination of Channel "i"

$\bar{W}(\theta_m)$ = the angular correlation function at an angle θ_m averaged over the solid angles used.

$\dot{N}_i$, the counting rate in Channel "i", can also be expressed as a function of certain of these same parameters.

$$\dot{N}_i = \Omega_i \phi_i \dot{N}_o \sum_j \epsilon_{ij} \alpha_{ij} \rho_{ij} + \dot{N}_{ib} \quad (7)$$

where

ϕ_i = the number of gamma rays "i" per disintegration

$\dot{N}_{ib}$ = the background counting rate in channel "i"

From Equations (5) and (6) we get for the correlation function,

$$\bar{W}(\theta_m) = \frac{\left\{ \frac{\dot{C}_g}{f \dot{N}_o} \right\}_m}{\left\{ \frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{f \dot{N}_o} \right\}_m} \quad (8)$$

where f is the appropriate function of the ϵ 's, α 's, ρ 's, and ϕ 's.

By combining Equations (7) and (8), we get for the correlation function

$$\bar{W}(\theta_m) = \left\{ \frac{(\dot{C}_t - \dot{C}_a - \dot{C}_b) \dot{N}_o g}{(\dot{N}_1 - \dot{N}_{1b}) (\dot{N}_2 - \dot{N}_{2b})} \right\}_m \quad (9)$$

where g is a function of the ε 's, α 's, Q 's, Ω 's θ 's.

In this form $W(\theta_m)$ is relatively insensitive to equipment stability. Therefore, it is only necessary to calculate the modified correlation function given by

$$\bar{W}'(\theta_m) = \frac{\bar{W}(\theta_m)}{g \dot{N}_o} = \left\{ \frac{(\dot{C}_t - \dot{C}_a - \dot{C}_b)}{(\dot{N}_1 - \dot{N}_{1b}) (\dot{N}_2 - \dot{N}_{2b})} \right\}_m \quad (10)$$

The correlation runs were done with the movable detector at seven angles: 90° , 105° , 120° , 135° , 150° , 165° , and 180° . A minimum of six two-hour counting periods were completed at each angle, and the angular order in which they were taken was varied to minimize any systematic fluctuations. Each run yielded single channel counting rates of approximately 1200 counts per second and a total coincidence rate of approximately 1.1 counts per second.

Before the experimental results can be compared to theory, the data must be checked and corrected, if necessary, for the various deviations from the ideal arrangement, i.e., centered point source, no spurious coincidences due to the coincidence resolving time, no scattering, no background, and perfect stability of the electronic equipment. In addition, the theoretical correlation function must be corrected for non-zero solid angle detectors. The methods for accounting for these effects are discussed in the following paragraphs.

A. SOURCE SIZE AND POSITIONING

As a test of the positioning of the source in the center of the correlation table, the integral counting rate of a portion of the Cobalt-60 spectrum was measured in each channel as a function of the angle between the counters. This was done by Verser and checked again after the base of the correlation table had been changed. Within statistical expectations, the counting rates were constant. The source has a volume of about 0.001 cubic inches and can be regarded as a point source at the distance at which the detectors were placed from it.

B. SCATTERING

Compton scattering occurring outside the detectors can give rise to unwanted coincidences. These in general will tend to smear out the measured correlation function. This problem is minimized by use of scintillation crystals as detectors and accepting only the full-energy peaks of the desired gamma rays. The method for determining the pulse height selection limits has been discussed in detail by Verser.

C. BACKGROUND CORRECTION

With the discriminators at the same settings as were used during the correlation runs, background runs were made before and after the correlation runs. The background coincidence counting rate was negligibly small and the background rate of each channel was such as to yield total background counts of the order of 0.4 percent of the total counts in each channel during the correlation runs. These background rates were used as corrections to the gross counting rates obtained during correlation runs.

D. DETERMINATION OF GENUINE COINCIDENCE RATE

Since the background coincidence counting rate proved experimentally

to be negligible, Equation (5) becomes

$$\dot{C}_g = \dot{C}_t - \dot{C}_a$$

For the total counting time, T , the total number of coincidences is $\dot{C}_t T$ and the standard deviation in the total coincidence rate is

$$\sigma_t = \sqrt{\frac{\dot{C}_t}{T}} \quad (11)$$

Therefore, the standard deviation of the genuine coincidence rate is

$$\sigma_g^2 = \sigma_t^2 + \sigma_a^2 = \frac{\dot{C}_t}{T} + \frac{\dot{C}_a}{T} \quad (12)$$

The accidental coincidence rate is given by

$$\dot{C}_a = 2\tau_r \dot{N}_1 \dot{N}_2 \sim 2\tau_r \dot{N}_o^2 \quad (13)$$

where

τ_r = Coincidence resolving time of the coincidence analyzer.

In order to minimize the accidental coincidence rate, the source strength must be kept as small as possible. However, if the source strength is decreased, the counting time must be increased to obtain a specified precision in the counting rate. Thus, a compromise must be reached between precision and counting time.

The smallest resolving time obtainable with the present equipment is experimentally determined to be

$$\tau_r = (0.1820 \pm 0.0016) \text{ microseconds;}$$

this resulted in an accidental coincidence rate that was about 30% of the

total coincidence rate. The approximate source strength of the water solution of CoCl_2 used in this experiment was 0.05 millicuries of Cobalt-60.

E. REFERENCE COUNTING RATE

With the discriminator in each channel adjusted to accept only the full-energy peaks of the desired gamma rays, the integral counting rate of the Cobalt-60 spectrum in each channel was determined. This gave a reference counting rate for each channel. During the course of the correlation runs, either the discriminator settings or the gains of the linear amplifiers were adjusted before each run so that, the integral counting rate agreed within ± 5 cps with these reference rates (Table 1).

TABLE 1

REFERENCE COUNTING RATES
$N_1 = (1085.26 \pm 0.57) \text{ cps}$
$N_2 = (1117.32 \pm 0.59) \text{ cps}$

As a measure of the gain fluctuations during each counting run, the integral counting rate of each channel was measured after the run using the same discriminator setting that was employed during the run. The difference between this counting rate and the reference counting for that channel was determined. If the variation exceeded ± 20 cps in either channel, the run was discarded.

This procedure resulted in about 30% of the runs being discarded because they fell outside of the maximum acceptable fluctuation. This indicates that the electronic system is not as stable as it should be. A check of the line voltage revealed substantial fluctuations during any 24-hour period. The temperature of the room was not controlled in any manner and varied considerably. These could have been the major causes of the large counting rate fluctuations since the discriminators are highly sensitive to both temperature and voltage variations.

F. SOLID ANGLE CORRECTIONS

The solid angle correction which must be applied to the theoretical correlation function to account for the non-zero solid angle of the detectors and enable a comparison to be made with the measured function is described by Rose (2). The correction for two cylindrical crystals whose axes intersect at the source involves the numerical evaluation of integrals of the form

$$I_{n,i} = \int_0^{\gamma_i} P_n(\cos \theta) \{1 - e^{-\gamma_i X_i(\theta)}\} \sin \theta d\theta \quad (14)$$

where

γ_i = the full-energy absorption coefficient of the detector in Channel "i" for the gamma ray;

γ_i = the half-angle subtended by the front face of the crystal in Channel "i";

$$X_i(\theta) = t_i \sec \theta \quad \text{for } 0 \leq \theta \leq \tan^{-1} \frac{r_i}{h_i + t_i} ;$$

$$X_i(\theta) = r_i \csc \theta - h_i \sec \theta \quad \text{for } \tan^{-1} \frac{r_i}{h_i + t_i} \leq \theta \leq \gamma_i ;$$

where

h_i = the distance from the source to the crystal in Channel "i";

t_i = the thickness of the crystal in Channel "i",

r_i = the radius of the crystal in Channel "i".

The attenuation factors, Q_n , are functions of these integrals:

$$Q_n = \begin{bmatrix} \frac{I_{n,1}}{I_{o,1}} \\ \frac{I_{n,2}}{I_{o,2}} \end{bmatrix} \quad (15)$$

The corrected correlation function becomes

$$\bar{W}(\theta) = \sum_{n=0}^{N_{\max}} Q_n A_n P_n(\cos \theta)$$

CHAPTER V EXPERIMENTAL RESULTS

The modified correlation function for the k^{th} run at angle θ_m given by Equation (10) is

$$\bar{W}'_k(\theta_m) = \left\{ \frac{\dot{C}_t - \dot{C}_a - \dot{C}_b}{(\dot{N}_1 - \dot{N}_{1b}) (\dot{N}_2 - \dot{N}_{2b})} \right\}_k$$

This means that the seven counting rates $\dot{C}_t$, $\dot{C}_a$, $\dot{C}_b$, $\dot{N}_1$, $\dot{N}_{1b}$, $\dot{N}_2$, and $\dot{N}_{2b}$ must be determined for each run at each angle and the standard deviation of each rate calculated.

The background counting rates $\dot{N}_{1b}$ and $\dot{N}_{2b}$ for each run were experimentally determined. The single-channel counting rates corrected for scaling losses yielded $\dot{N}_1$ and $\dot{N}_2$. The accidental counting rates were calculated for each run from Equation (13). The total coincidence counting rate, $\dot{C}_t$, was experimentally determined. The background coincidence rate, $\dot{C}_b$, was negligible throughout the experiment.

The experimental value of the modified correlation function $\bar{W}'_k(\theta_m)$ and its standard deviation were calculated for each run at each angle. From these the weighted mean $\bar{W}'(\theta_m)$ and its standard deviation were computed for each angle.

The weighted mean of the measurements taken at each angle was determined by using the inverse square of the standard deviation of each measurement as a weighting factor:

$$\bar{W}'(\theta_m) = \frac{\sum_{k=1}^{N_m} \frac{\bar{W}'_k(\theta_m)}{\sigma_k^2}}{\sum_{k=1}^{N_m} \frac{1}{\sigma_k^2}} \quad (18)$$

where N_m = number of runs at the angle θ_m .

The standard deviation of the weighted mean ($\bar{W}'$) was calculated from the individual standard deviations:

$$\frac{1}{\sigma^2(\bar{W}')} = \sum_1^{N_m} \frac{1}{\sigma_k^2} \quad (19)$$

A comparison between the standard deviations of the means calculated from Equation (19) and those calculated from

$$\sigma^2(\bar{W}') = \sum_1^{N_m} \frac{[\bar{W}'(\theta_m) - \bar{W}(\theta)]^2}{N_m(N_m - 1)} \quad (20)$$

revealed no significant differences. Therefore the standard deviation obtained from Equation (19) were used in subsequent calculations and the method discussed in paragraph E Chapter IV for treating gain instabilities is realistic.

The values of the weighted means and their standard deviations are tabulated in Table 2.

TABLE 2
The Weighted Means $\bar{W}'(\theta_m)$

θ_m (degrees)	Weighted Mean	Standard Deviation
90	5046	45
105	4925	33
120	5109	21
135	5211	36
150	5556	35
165	5667	24
180	5907	43

A curve of the form $\bar{W}'(\theta) = \sum A_n' P_n(\cos\theta)$ was fitted to the experimental $\bar{W}'(\theta_m)$ by the method of least squares as outlined by Rose (2). This analysis was programmed to be carried out by the 1604 computer. (See Appendix II for details).

The values of A_n' are given by the matrix equation

$$\|A'\| = \|A^T \omega A\|^{-1} \cdot \|A^T\| \cdot \|\mathcal{L}\| \cdot \|\mathcal{U}\| \quad (21)$$

where

$\|A\|$ = the 7×3 matrix consisting of the Legendre Polynomials, P_0 , P_2 , and P_4 , evaluated at the seven angles (Figure 5A).

$\|A^T\|$ = the transposed A matrix

$\|\omega\|$ = a diagonal matrix with elements consisting of the inverse squares of the standard deviations of the experimental $\bar{W}'(\theta_m)$ (Figure 5B)

$\|\mathcal{U}\|$ = a one column matrix whose elements are the experimental values of $\bar{W}'(\theta_m)$ (Figure 5C)

$\|A'\|$ = the one column matrix whose elements are respectively the least-square coefficients A_0' , A_2' and A_4' (Figure 5D)

$\|A^T \omega A\|^{-1}$ = the inverse of the matrix obtained by multiplying the three designated matrices together. The diagonal terms of this matrix are the squares of the standard deviations of the least-square coefficients, A_n' .

The experimental values for the coefficients A_n' and their standard deviations, normalized so that $A_0' = 1$, are listed in Table 3. The corresponding values from Verser's work are included for comparison.

TABLE 3
Least Square Coefficients

Verser		This Work
A'_0	1.0000 ± 0.0034	1.0000 ± 0.0026
A'_2	0.0961 ± 0.0055	0.0971 ± 0.0057
A'_4	0.0339 ± 0.0071	0.0231 ± 0.0066

MATRIX CONFIGURATIONS

$P_0(\cos 90^\circ)$	$P_2(\cos 90^\circ)$	$P_4(\cos 90^\circ)$
$P_0(\cos 105^\circ)$	$P_2(\cos 105^\circ)$	$P_4(\cos 105^\circ)$
$P_0(\cos 120^\circ)$	$P_2(\cos 120^\circ)$	$P_4(\cos 120^\circ)$
$P_0(\cos 135^\circ)$	$P_2(\cos 135^\circ)$	$P_4(\cos 135^\circ)$
$P_0(\cos 150^\circ)$	$P_2(\cos 150^\circ)$	$P_4(\cos 150^\circ)$
$P_0(\cos 165^\circ)$	$P_2(\cos 165^\circ)$	$P_4(\cos 165^\circ)$
$P_0(\cos 180^\circ)$	$P_2(\cos 180^\circ)$	$P_4(\cos 180^\circ)$

(A)

$\sigma^{-2}(90^\circ)$	0	0	0	0	0	0
0	$\sigma^{-2}(105^\circ)$	0	0	0	0	0
0	0	$\sigma^{-2}(120^\circ)$	0	0	0	0
0	0	0	$\sigma^{-2}(135^\circ)$	0	0	0
0	0	0	0	$\sigma^{-2}(150^\circ)$	0	0
0	0	0	0	0	$\sigma^{-2}(165^\circ)$	0
0	0	0	0	0	0	$\sigma^{-2}(180^\circ)$

(B)

$\bar{W}'(90^\circ)$
$\bar{W}'(105^\circ)$
$\bar{W}'(120^\circ)$
$\bar{W}'(135^\circ)$
$\bar{W}'(150^\circ)$
$\bar{W}'(165^\circ)$
$\bar{W}'(180^\circ)$

(C)

A_0
A_2
A_4

(D)

FIGURE 5

A. Experimental Anisotropies

The anisotropy is defined:

$$\bar{R} = \frac{\bar{W}(180^\circ) - \bar{W}(90^\circ)}{\bar{W}(90^\circ)} \quad (22)$$

The anisotropy for the least-square curve was calculated from the experimental correlation function. Since the anisotropy can be determined with much greater precision than can the least-square coefficients themselves, it provides a more sensitive means for comparing the experimental and theoretical functions. The experimental anisotropy is

$$\bar{R} = 0.167 \pm 0.013$$

The standard deviation was calculated by the formula presented by Klema and McGowan (6). The computer program for the calculation of $\bar{R}$ and its standard deviation is outlined in Appendix I.

CHAPTER VI

RESULTS AND CONCLUSIONS

A. COMPARISON BETWEEN EXPERIMENT AND THEORY

The experimental and corrected theoretical functions for this experiment are:

Experimental:

$$\begin{aligned}\bar{W}'(\theta) = & (1.0000 \pm 0.0026) + (0.0971 \pm 0.0057) P_2 \\ & + (0.0231 \pm 0.0066) P_4\end{aligned}$$

Theoretical:

$$\bar{W}(\theta) = 1.0000 \pm 0.0996 P_2 + 0.00838 P_4$$

The experimental anisotropy was calculated to be $\bar{R} = 0.167 \pm 0.013$ and is compared with Verser's value of $\bar{R} = 0.171 \pm 0.027$ and with the theoretical anisotropy corrected for the solid angle, $\bar{R} = 0.161$.

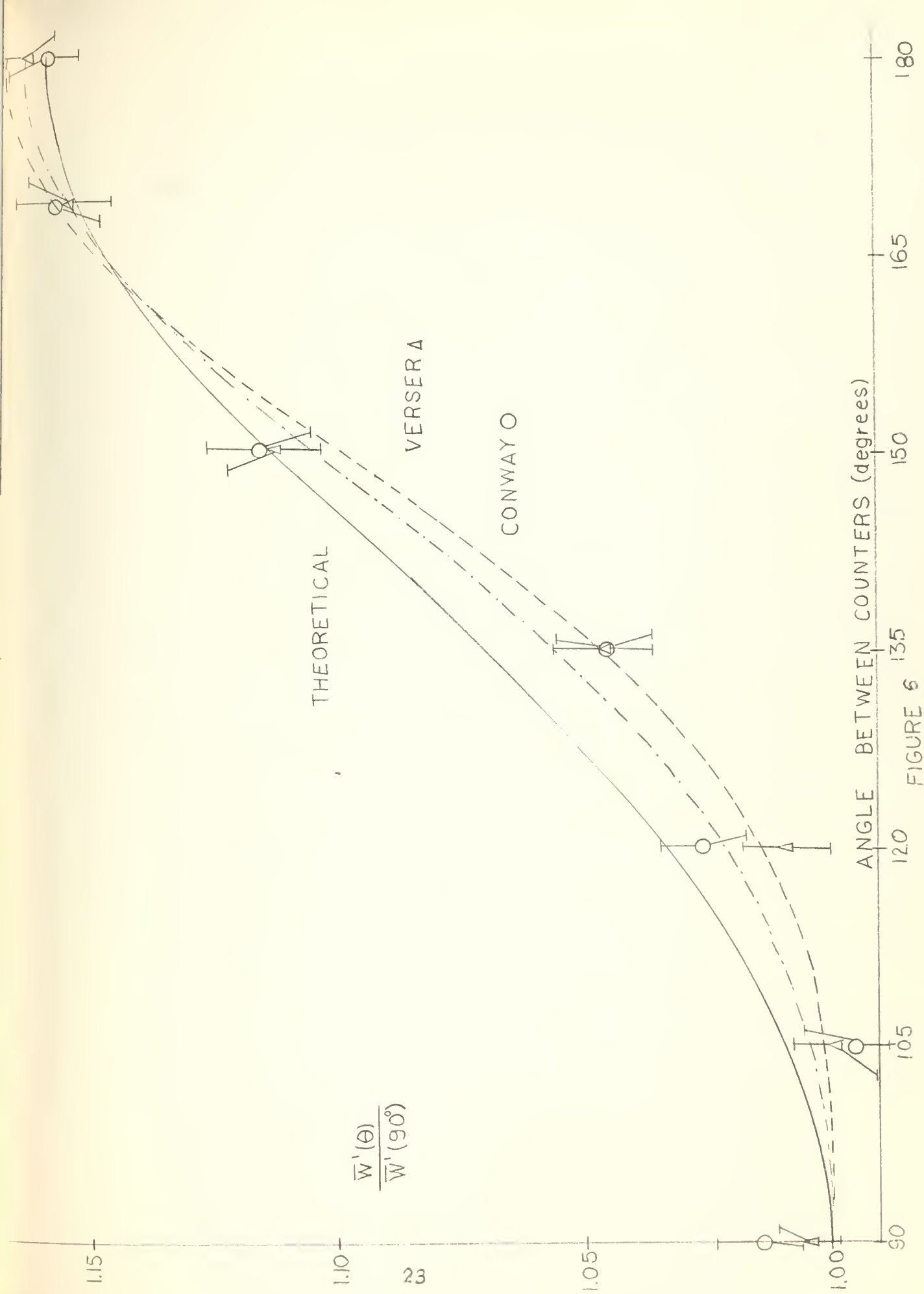
Figure 6 shows the experimental results and their standard deviations for this work and that of Verser. Also shown are the least-square correlation curves for both sets of data and the corrected theoretical correlation curve. All the curves have been normalized to unity at $\theta = 90^\circ$.

B. DISCUSSION AND CONCLUSIONS

From Figure 6, it can be seen that the curve obtained in this work agrees with that obtained by Verser. Both of these curves show an apparently real dip in the region from 105° to 135° . It is only a remote possibility that this dip can be attributed to statistical fluctuations, and it is unlikely to be due to instrumental effects.

Two conjectures of possible mechanisms are:

- (a) The source may have crystallized resulting in preferential alignment of the nuclei within the crystal due to internal electric fields.



- (b) The ferromagnetic properties of Cobalt could have led to a preferential alignment of the nuclei in the earth's magnetic field.

The following series of experiments are suggested for future work.

- (a) The results for measurements conducted for angles between 180° and 270° should be compared with those already obtained.
- (b) In order to check on the possible effects of orientation due to crystalline electric fields, the experiment should be repeated with the present source at various orientations relative to the fixed counter.
- (c) In order to check on the possibility of orientation by magnetic effects the source should be placed in a magnetic field of known direction and the measurements repeated.
- (d) A correlation curve using a powdered Cobalt-60 source in place of the present source should be obtained for comparison.

These experiments would determine conclusively if any effects causing preferential nuclear orientation are present.

The following instrumentation improvements are suggested in order to improve the stability of the equipment.

- (a) A very stable power supply should be purchased to aid in preventing the line voltage fluctuations from interfering with the electronic system.
- (b) The effect of temperature variations on the electronic system can be minimized by placing the equipment in a temperature controlled room for conducting future work.
- (c) A slow coincidence unit whose resolving time is independent of the counting rate should be obtained.

The precision of the results should be improved by the addition of a fast coincidence channel working in conjunction with the slow coincidence unit to reduce the number of accidental coincidences.

Since the experimental curves using Cobalt-60 have not agreed with the theoretical curve, the experiments on Cobalt-60 should be continued until the source of the distortion is ascertained. Perhaps the effect can be related to the physical properties of the CoCl_2 source.

APPENDIX I

Least-Square Fit of Experimental Results

The comparison of the experimental correlation function to the functional form of the theoretical correlation function given by Equation (1) is accomplished by the method of least-squares, as outlined by Rose (2). The analysis requires the solution of Equation (20) for the values of A'_n .

The computer solution of the matrix equation, like the solid angle calculation, is carried out in floating point format. In addition to the solution for the values of A'_n , the program also calculates the anisotropy by Equation (21), and its standard deviation by the formula presented by Klema and McGowan (6). A flow sheet outline of the program is given in Figure (7). In order to provide a certain amount of flexibility to the program, the angles used have been left as a parameter to be supplied. The program as written is, however, limited to seven different angular positions. The parameters needed for the program may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order:

B1 = weighted means of the correlation function in ascending angular order.

B2 = the standard deviations of the weighted means in the same order as above.

B3 = the values of the angles used in ascending order.

The program is available for future use on both biotape in machine language, and IBM cards in assembly language. The biotape contains the following:

1. The main program for calculation of A'_n
2. The program of normalization of the A'_n
3. The program for calculation of the resulting correlation function
4. The normalization of the correlation function
5. The calculation of the anisotropy

LEAST-SQUARE FIT FLOW CHART

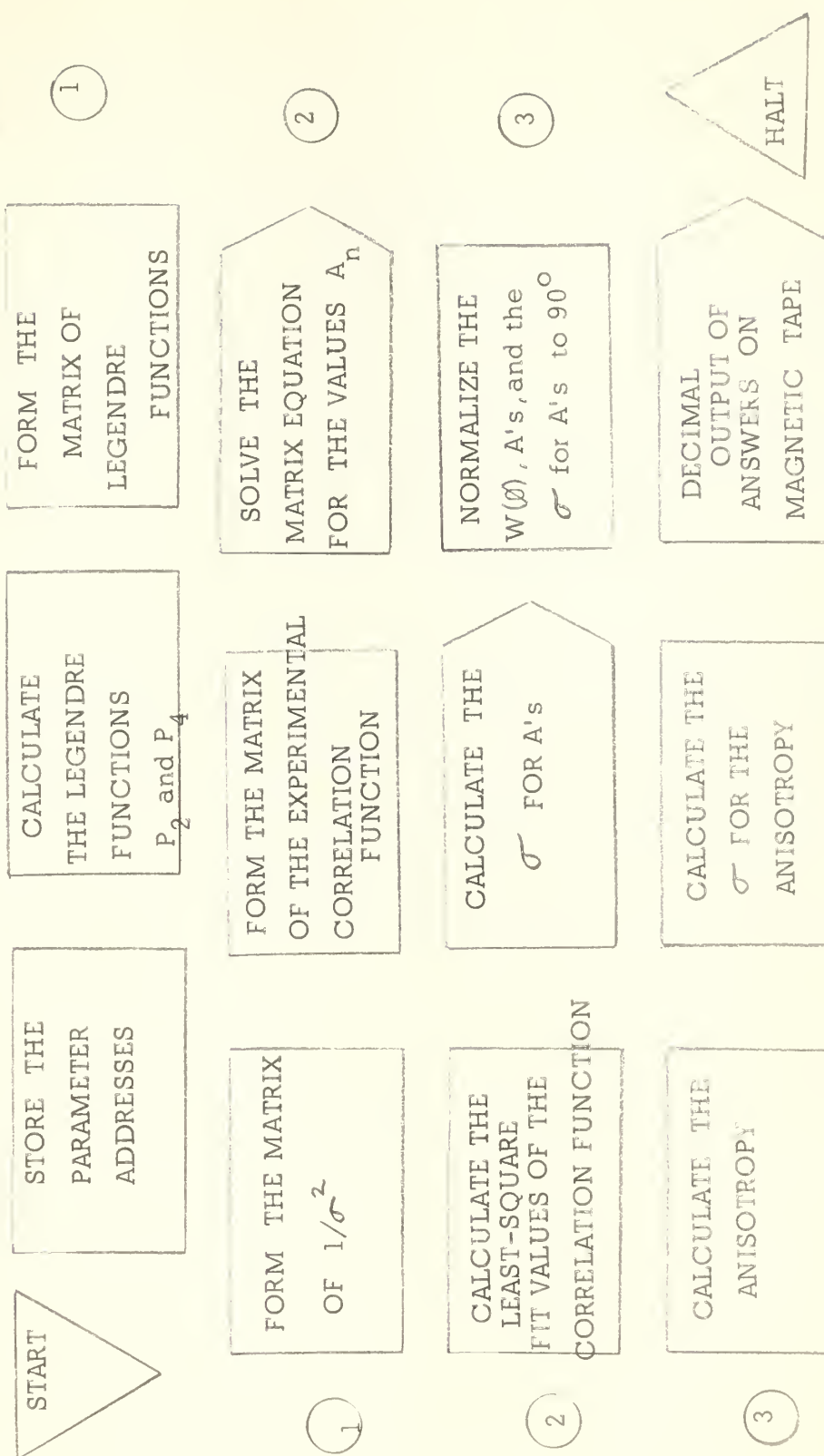


FIGURE 7

6. The calculation of the standard deviation for the anisotropy
7. The subroutines
 - a. Floating Point Sine-Cosine
 - b. Floating Point Square Root
 - c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Lines 1 thru 3	The matrix inverse
Lines 4 thru 6	Check answer; included in the program is a check of the inverse which consists of multiplying the inverse by the original matrix
Line 7	The values of A'_0 , A'_2 and A'_4
Line 8	The standard deviations of the A'_n
Line 9 thru 13	The resulting correlation functions
Line 14 and 15	The normalized correlation functions
Line 16	The normalized A'_n
Line 17	The normalized standard deviations of the A'_n
Line 18	The anisotropy
Line 19	The square of the standard deviation of the anisotropy

STATISTICAL ANALYSIS PROGRAM

```

                                ORG      12000
                                REM      BURTON J CONWAY APRIL 1961
                                REM      LEAST SQUARE FIT OF ANGULAR
                                REM      CORRELATION DATA.
                                REM      MUST BE SUPPLIED WITH
                                REM      PARAMETER ADDRESSES AS FOLLOWS.
                                REM      B1  CORRELATION FUNCTION.
                                REM      B2  SIGMA OF CORRELATION FUNCTION.
                                REM      B3  ANGLES USED IN DEGREES.
ZEUS      EQU      13000
RHO       EQU      13100
TRANS     EQU      13200
ATW       EQU      13230
ATWA      EQU      13260
INVER     EQU      13500
CHECK     EQU      13520
. IAT      EQU      13540
IATW      EQU      13570
ANS       EQU      13620
FINIS     EQU      13630
SINFL     EQU      60000
MATRIX    EQU      10000

```


		ANISO	ECU	13624	
12000	56 1 12045		SIU	1 FORMMU	
	50 1 00000		ENI	1 0	
12001	57 2 12032		SIL	2 SIGMA	
	56 2 12033		SIU	2 SIGMA+1	
12002	50 2 00000		ENI	2 0	
	50 0 00000		ENI	0 0	
12003	56 3 12004		SIU	3 /+1	
	50 3 00000		ENI	3 0	
12004	12 1 00000	START	LDA	1 0	
	32 0 12512		FMU	0 CONV	
12005	75 4 60001		SLJ	4 SINFL+1	
	50 0 00000		ENI	0 0	
12006	50 0 00000		ENI	0 0	
	50 0 00000		ENI	0 0	
12007	50 0 00000		ENI	0 0	
	50 0 00000		ENI	0 0	
12010	20 1 12463		STA	1 TEMP	
	50 0 00000		ENI	0 0	
12011	54 1 00006		ISK	1 6	
	75 0 12004		SLJ	0 START	
12012	12 1 12463	NEXT	LDA	1 TEMP	STARTS FORMATION
	32 1 12463		FMU	1 TEMP	OF THE LEG. POL.

12013	20 0 12461		STA 0 DON
	32 0 12320		FMU 0 FLT2
12014	31 0 12316		FSB 0 FLT
	33 0 12317		FDV 0 FLT1
12015	20 1 12326		STA 1 WORK2
	12 0 12461		LDA 0 DON
12016	32 0 12322		FMU 0 FLT4
	20 0 12462		STA 0 DON+1
12017	12 0 12461		LDA 0 DON
	32 0 12461		FMU 0 DON
12020	32 0 12323		FMU 0 FLT5
	31 0 12462		FSB 0 DON+1
12021	30 0 12320		FAD 0 FLT2
	33 0 12321		FDV 0 FLT3
12022	20 1 12335		STA 1 WORK4
	50 0 00000		ENI 0 0
12023	54 1 00006		ISK 1 6
	75 0 12012		SLJ 0 NEXT
12024	12 0 12325	FORM	LDA 0 WORK1
	20 2 12434		STA 2 ABLE
12025	51 2 00001		INI 2 1
	12 1 12326		LDA 1 WORK2
12026	20 2 12434		STA 2 ABLE
	51 2 00001		INI 2 1

12027	12 1 12335		LDA 1 WORK4
	20 2 12434		STA 2 ABLE
12030	51 2 00001		INI 2 1
	50 0 00000		ENI 0 0
12031	54 1 00006		ISK 1 6
	75 0 12024		SLJ 0 FORM
12032	12 0 12316	SIGMA	LDA 0 FLT
	33 1 00000		FDV 1 0
12033	33 1 00000		FDV 1 0
	20 1 12463		STA 1 TEMP
12034	54 1 00006		ISK 1 6
	75 0 12032		SLJ 0 SIGMA
12035	50 2 00000		ENI 2 0
	50 1 00000		ENI 1 0
12036	12 1 12353	FORMCAD	LDA 1 CAD
	22 0 12043		AJP 0 /+5
12037	12 2 12463		LDA 2 TEMP
	20 1 12353		STA 1 CAD
12040	51 1 00001		INI 1 1
	50 0 00000		ENI 0 0
12041	54 2 00006		ISK 2 6
	75 0 12036		SLJ 0 FORMCAD

12042	75 0 12044	SLJ 0 /+2	
	50 0 00000	ENI 0 0	
12043	51 1 00001	INI 1 1	
	75 0 12036	SLJ 0 FORMCAD	
12044	50 1 00000	ENI 1 0	
	50 2 00000	ENI 2 0	
12045	12 1 00000 FORMMU	LDA 1 0	
	20 1 12344	STA 1 MU	
12046	54 1 00006	ISK 1 6	
	75 0 12045	SLJ 0 FORMMU	
12047	50 1 00000	ENI 1 0	
	50 2 00000	ENI 2 0	
12050	75 4 10000	SLJ 4 MATRIX	TRANSPOSE
	50 0 00000	ENI 0 0	
12051	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12052	50 0 00000	ENI 0 0	
	50 0 00002	ENI 0 2	
12053	50 0 00007	ENI 0 7	
	50 0 12434	ENI 0 ABLE	
12054	50 0 00003	ENI 0 3	
	50 0 06626	ENI 0 6626	
12055	50 0 00000	ENI 0 0	
	50 0 13200	ENI 0 TRANS	

12056	75 4 10000	SLJ 4 MATRIX	ATW
	50 0 00000	ENI 0 0	
12057	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12060	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12061	50 0 00003	ENI 0 3	
	50 0 13200	ENI 0 TRANS	
12062	50 0 00007	ENI 0 7	
	50 0 12353	ENI 0 CAD	
12063	50 0 00007	ENI 0 7	
	50 0 13230	ENI 0 ATW	
12064	75 4 10000	SLJ 4 MATRIX	ATWA
	50 0 00000	ENI 0 0	
12065	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12066	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12067	50 0 00003	ENI 0 3	
	50 0 13230	ENI 0 ATW	
12070	50 0 00007	ENI 0 7	
	50 0 12434	ENI 0 ABLE	

12071	50 0 00003	ENI 0 3	
	50 0 13260	ENI 0 ATWA	
12072	75 4 10000	SLJ 4 MATRIX	INVERSE
	50 0 00000	ENI 0 0	
12073	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12074	50 0 00000	ENI 0 0	
	50 0 00005	ENI 0 5	
12075	50 0 00003	ENI 0 3	
	50 0 13260	ENI 0 ATWA	
12076	50 0 00044	ENI 0 36D	
	50 0 13272	ENI 0 ATWA+12	
12077	50 0 00000	ENI 0 0	
	50 0 13500	ENI 0 INVER	
12100	75 4 10000	SLJ 4 MATRIX	CHECK
	50 0 00000	ENI 0 0	
12101	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12102	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12103	50 0 00003	ENI 0 3	
	50 0 13500	ENI 0 INVER	
12104	50 0 00003	ENI 0 3	
	50 0 13260	ENI 0 ATWA	

12105	50 0 00003	ENI 0 3	
	50 0 13520	ENI 0 CHECK	
12106	75 4 10000	SLJ 4 MATRIX	IAT
	50 0 00000	ENI 0 0	
12107	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12110	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12111	50 0 00003	ENI 0 3	
	50 0 13500	ENI 0 INVER	
12112	50 0 00003	ENI 0 3	
	50 0 13200	ENI 0 TRANS	
12113	50 0 00007	ENI 0 7	
	50 0 13540	ENI 0 IAT	
12114	75 4 10000	SLJ 4 MATRIX	IATW
	50 0 00000	ENI 0 0	
12115	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12116	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12117	50 0 00003	ENI 0 3	
	50 0 13540	ENI 0 IAT	

12120	50 0 00007	ENI 0 7	
	50 0 12353	ENI 0 CAD	
12121	50 0 00007	ENI 0 7	
	50 0 13570	ENI 0 IATW	
12122	75 4 10000	SLJ 4 MATRIX	ANS
	50 0 00000	ENI 0 0	
12123	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12124	50 0 00000	ENI 0 0	
	50 0 00004	ENI 0 4	
12125	50 0 00003	ENI 0 3	
	50 0 13570	ENI 0 IATW	
12126	50 0 00007	ENI 0 7	
	50 0 12344	ENI 0 MU	
12127	50 0 00001	ENI 0 1	
	50 0 13620	ENI 0 ANS	
12130	50 4 00000	ENI 4 0	
	50 5 00000	ENI 5 0	
12131	50 6 00000	ENI 6 0	
	50 1 00000	ENI 1 0	
12132	50 2 00000	ENI 2 0	
	50 3 00000	ENI 3 0	
12133	54 1 77777	ISK 1 77777	
	75 0 12133	SLJ 0 /	

12134	50 0 00000	ENI 0 0
	74 7 42040	EXF 7 42040
12135	75 4 71000	SLJ 4 71000
	50 0 00000	ENI 0 0
12136	01 0 13500	01 0 INVER
	04 0 00001	04 0 1
12137	12 0 12315	LDA 0 MIKE
	70 0 12136	RAD 0 /-1
12140	54 4 00002	ISK 4 2
	75 0 12135	SLJ 0 /-3
12141	54 1 77777	ISK 1 77777
	75 0 12141	SLJ 0 /
12142	54 1 77777	ISK 1 77777
	75 0 12142	SLJ 0 /
12143	50 0 00000	ENI 0 0
	74 7 42040	EXF 7 42040
12144	75 4 71000	SLJ 4 71000
	50 0 00000	ENI 0 0
12145	01 0 13520	01 0 CHECK
	04 0 00004	04 0 4
12146	12 0 12315	LDA 0 MIKE
	70 0 12145	RAD 0 /-1

12147	54 4 00002	ISK 4 2	
	75 0 12144	SLJ 0 /-3	
12150	54 1 77777	ISK 1 77777	
	75 0 12150	SLJ 0 /	
12151	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12152	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	
12153	01 0 13620	01 0 ANS	
	04 0 00007	04 0 7	
		REM STARTS FORMATION OF THE	
		REM CORRELATION FUNCTION	
12154	12 0 13620 DUMP	LDA 0 ANS	
	32 4 12434	FMU 4 ABLE	
12155	20 0 13100	STA 0 RHO	AOPO IN STORAGE
	51 4 00001	INI 4 1	
12156	12 0 13621	LDA 0 ANS+1	
	32 4 12434	FMU 4 ABLE	A2P2 IN A REG
12157	30 0 13100	FAD 0 RHO	AOPO+A2P2 IN THE
	20 0 13100	STA 0 RHO	A REGISTER
12160	12 0 13622	LDA 0 ANS+2	
	51 4 00001	INI 4 1	
12161	32 4 12434	FMU 4 ABLE	A4P4 IN A REG
	30 0 13100	FAD 0 RHO	SUM IN A REG

12162	20 6 13000	STA 6 ZEUS	ANS TO STORAGE
	51 6 00003	INI 6 3	
12163	54 4 00024	ISK 4 24	
	75 0 12154	SLJ 0 DUMP	
12164	12 2 13500	LDA 2 INVER	
	75 4 12527	SLJ 4 SQRFL	
12165	50 0 00000	ENI 0 0	
	50 0 00000	ENI 0 0	
12166	20 1 12501	STA 1 TTA	
	51 2 00004	INI 2 4	
12167	54 1 00002	ISK 1 2	
	75 0 12164	SLJ 0 /-3	
12170	50 1 00000	ENI 1 0	
	50 2 00000	ENI 2 0	
12171	50 3 00000	ENI 3 0	
	50 4 00000	ENI 4 0	
12172	54 1 77777	ISK 1 77777	
	75 0 12172	SLJ 0 /	
12173	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12174	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	

12175	01 0 12501	01 0 TTA	
	04 0 00010	04 0 10	
12176	54 1 77777	ISK 1 77777	
	75 0 12176	SLJ 0 /	
12177	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12200	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	
12201	01 0 13000	01 0 ZEUS	
	04 0 00011	04 0 11	
12202	12 0 12315	LDA 0 MIKE	
	70 0 12201	RAD 0 /-1	
12203	54 5 00004	ISK 5 4	
	75 0 12200	SLJ 0 /-3	
12204	12 1 13000	LDA 1 ZEUS	NORMALIZES THE
	33 0 13000	FDV 0 ZEUS	CORRELATION
12205	20 2 12472	STA 2 NORM	FUNCTION
	51 1 00003	INI 1 3	
12206	54 2 00006	ISK 2 6	
	75 0 12204	SLJ 0 /-2	
12207	54 1 77777	ISK 1 77777	
	75 0 12207	SLJ 0 /	
12210	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	

12211	75 4 71000	SLJ 4 71000	DUMPS THE
	50 0 00000	ENI 0 0	NORMALIZED
12212	01 0 12472	01 0 NORM	CORRELATION
	04 0 00016	04 0 16	FUNCTION
12213	12 0 12315	LDA 0 MIKE	
	70 0 12212	RAD 0 /-1	
12214	54 2 00001	ISK 2 1	
	75 0 12211	SLJ 0 /-3	
12215	50 1 00000	ENI 1 0	
	50 0 00000	ENI 0 0	
12216	12 1 13620	LDA 1 ANS	
	33 0 13620	FDV 0 ANS	
12217	20 1 12507	STA 1 AN	
	50 0 00000	ENI 0 0	
12220	54 1 00002	ISK 1 2	
	75 0 12216	SLJ 0 /-2	
12221	54 1 77777	ISK 1 77777	
	75 0 12221	SLJ 0 /	
12222	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12223	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	

12224	01 0 12507	01 0 AN	
	04 0 00020	04 0 20	
12225	12 1 12501	LDA 1 TTA	NORMALIZES THE
	33 0 13000	FDV 0 ZEUS	SIGMAS FOR A
12226	20 1 12504	STA 1 TTAN	
	50 0 00000	ENI 0 0	
12227	54 1 00002	ISK 1 2	
	75 0 12225	SLJ 0 /-2	
12230	54 1 77777	ISK 1 77777	
	75 0 12230	SLJ 0 /	
12231	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12232	75 4 71000	SLJ 4 71000	
	50 0 00000	ENI 0 0	
12233	01 0 12504	01 0 TTAN	
	04 0 00021	04 0 21	
12234	12 0 13022	LDA 0 ZEUS+22	
	31 0 13000	FSB 0 ZEUS	
12235	33 0 13000	FDV 0 ZEUS	
	20 0 13624	STA 0 ANISO	
12236	54 1 77777	ISK 1 77777	
	75 0 12236	SLJ 0 /	
12237	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	

12240	75 4 71000	SLJ 4 71000
	50 0 00000	ENI 0 0
12241	01 0 13624	01 0 ANISO
	04 0 00022	04 0 22
12242	12 0 12314	LDA 0 ZRO
	20 0 12514	STA 0 ROB
12243	12 1 12344	AVG LDA 1 MU
	31 2 13000	FSB 2 ZEUS
12244	20 0 12513	STA 0 EBSIL
	32 0 12513	FMU 0 EBSIL
12245	32 3 12353	FMU 3 CAD
	30 0 12514	FAD 0 ROB
12246	20 0 12514	STA 0 ROB
	51 2 00003	INI 2 3
12247	51 3 00010	INI 3 10
	50 0 00000	ENI 0 0
12250	54 1 00006	ISK 1 6
	75 0 12243	SLJ 0 AVG
12251	12 0 12514	LDA 0 ROB
	33 0 12324	FDV 0 FLT6
12252	20 0 12514	STA 0 ROB
	50 2 00000	ENI 2 0

12253	50 3 00000	ENI 3 0
	50 1 00000	ENI 1 0
12254	12 0 12514	LDA 0 ROB
	32 1 13500	FMU 1 INVER
12255	20 2 12515	STA 2 AXE
	51 1 00004	INI 1 4
12256	54 2 00002	ISK 2 2
	75 0 12254	SLJ 0 /-2
12257	12 0 12514	LDA 0 ROB
	32 0 13501	FMU 0 INVER+1
12260	20 0 12520	STA 0 COVO2
	12 0 12514	LDA 0 ROB
12261	32 0 13505	FMU 0 INVER+5
	20 0 12521	STA 0 COV24
12262	12 0 13621	LDA 0 ANS+1
	30 0 13622	FAD 0 ANS+2
12263	20 0 12522	STA 0 A24
	32 0 12522	FMU 0 A24
12264	20 0 12523	STA 0 A242
	12 0 12522	LDA 0 A24
12265	33 0 13620	FDV 0 ANS
	20 0 12524	STA 0 GET
12266	32 0 12524	FMU 0 GET
	20 0 12524	STA 0 GET

12267	12 0 12522	LDA 0 A24
	32 0 13620	FMU 0 ANS
12270	20 0 12522	STA 0 A24
	50 0 00000	ENI 0 0
12271	12 0 12521	LDA 0 COV24
	32 0 12317	FMU 0 FLT1
12272	30 0 12516	FAD 0 AXE+1
	30 0 12517	FAD 0 AXE+2
12273	33 0 12523	FDV 0 A242
	20 0 12525	STA 0 WIT
12274	12 0 12515	LDA 0 AXE
	33 0 13620	FDV 0 ANS
12275	33 0 13620	FDV 0 ANS
	30 0 12525	FAD 0 WIT
12276	20 0 12525	STA 0 WIT
	12 0 12520	LDA 0 COV02
12277	30 0 12521	FAD 0 COV24
	33 0 12522	FDV 0 A24
12300	32 0 12317	FMU 0 FLT1
	20 0 12526	STA 0 WIT+1
12301	12 0 12525	LDA 0 WIT
	31 0 12526	FSB 0 WIT+1

12302	32 0 12524		FMU 0 GET
	20 0 13630		STA 0 FINIS
12303	54 1 77777		ISK 1 77777
	75 0 12303		SLJ 0 /
12304	50 0 00000		ENI 0 0
	74 7 42040		EXF 7 42040
12305	75 4 71000		SLJ 4 71000
	50 0 00000		ENI 0 0
12306	01 0 13630		01 0 FINIS
	04 0 00025		04 0 25
12307	54 1 77777		ISK 1 77777
	75 0 12307		SLJ 0 /
12310	54 1 77777		ISK 1 77777
	75 0 12310		SLJ 0 /
12311	50 0 00000		ENI 0 0
	74 7 42040		EXF 7 42040
12312	74 0 42003		EXF 0 42003
	50 0 00000		ENI 0 0
12313	76 0 12000		SLS 0 12000
	50 0 00000		ENI 0 0
12314	00 0 00000	ZRO	OCT 0
	00 0 00000		
12315	00 0 00004	MIKE	0 0 4
	00 0 00001		0 0 1

12316	20 0 14000	FLT	DEC	1.0
	00 0 00000			
12317	20 0 24000	FLT1	DEC	2.0
	00 0 00000			
12320	20 0 26000	FLT2	DEC	3.0
	00 0 00000			
12321	20 0 44000	FLT3	DEC	8.0
	00 0 00000			
12322	20 0 57400	FLT4	DEC	30.0
	00 0 00000			
12323	20 0 64300	FLT5	DEC	35.0
	00 0 00000			
12324	20 0 34000	FLT6	DEC	4.0
	00 0 00000			
12325	20 0 14000	WORK1	DEC	1.0
	00 0 00000			
12326	00 0 00000	WORK2	BSS	7
	00 0 00000			
12335	00 0 00000	WORK4	BSS	7
	00 0 00000			
12344	17 5 34167	MJ	DEC	.5046D-6
	17 3 10477			

12345	17 5 34103	DEC	.4925D-6
	21 2 75007		
12346	17 5 34222	DEC	.5109D-6
	23 0 76631		
12347	17 5 34276	DEC	.5211D-6
	06 7 01135		
12350	17 5 34522	DEC	.5556D-6
	22 1 24417		
12351	17 5 34601	DEC	.5667D-6
	75 2 36515		
12352	17 5 34751	DEC	.5907D-6
	02 3 02276		
12353	20 7 07231	CAD DEC	.6574621D+17
	17 2 43106		
12354	00 0 00000	OCT	0
	00 0 00000		
12355	00 0 00000	OCT	0
	00 0 00000		
12356	00 0 00000	OCT	0
	00 0 00000		
12357	00 0 00000	OCT	0
	00 0 00000		
12360	00 0 00000	OCT	0
	00 0 00000		

12361	00 0 00000	OCT	0
	00 0 00000		
12362	00 0 00000	OCT	0
	00 0 00000		
12363	20 7 05367	DEC	.4938271D+17
	05 2 01171		
12364	00 0 00000	OCT	0
	00 0 00000		
12365	00 0 00000	OCT	0
	00 0 00000		
12366	00 0 00000	OCT	0
	00 0 00000		
12367	00 0 00000	OCT	0
	00 0 00000		
12370	00 0 00000	OCT	0
	00 0 00000		
12371	00 0 00000	OCT	0
	00 0 00000		
12372	00 0 00000	OCT	0
	00 0 00000		
12373	20 7 05015	DEC	.4526935D+17
	20 7 37137		

12374	00 0 00000	OCT	0
	00 0 00000		
12375	00 0 00000	OCT	0
	00 0 00000		
12376	00 0 00000	OCT	0
	00 0 00000		
12377	00 0 00000	OCT	0
	00 0 00000		
12400	00 0 00000	OCT	0
	00 0 00000		
12401	00 0 00000	OCT	0
	00 0 00000		
12402	00 0 00000	OCT	0
	00 0 00000		
12403	20 7 05176	DEC	.4725897D+17
	27 1 03164		
12404	00 0 00000	OCT	0
	00 0 00000		
12405	00 0 00000	OCT	0
	00 0 00000		
12406	00 0 00000	OCT	0
	00 0 00000		
12407	00 0 00000	OCT	0
	00 0 00000		

12410	00 0 00000	OCT	0
	00 0 00000		
12411	00 0 00000	OCT	0
	00 0 00000		
12412	00 0 00000	OCT	0
	00 0 00000		
12413	20 7 04477	DEC	.4164931D+17
	37 2 35173		
12414	00 0 00000	OCT	0
	00 0 00000		
12415	00 0 00000	OCT	0
	00 0 00000		
12416	00 0 00000	OCT	0
	00 0 00000		
12417	00 0 00000	OCT	0
	00 0 00000		
12420	00 0 00000	OCT	0
	00 0 00000		
12421	00 0 00000	OCT	0
	00 0 00000		
12422	00 0 00000	OCT	0
	00 0 00000		

12423	20 7 15041		DEC	.9124087D+17
	16 1 31752			
12424	00 0 00000		OCT	0
	00 0 00000			
12425	00 0 00000		OCT	0
	00 0 00000			
12426	00 0 00000		OCT	0
	00 0 00000			
12427	00 0 00000		OCT	0
	00 0 00000			
12430	00 0 00000		OCT	0
	00 0 00000			
12431	00 0 00000		OCT	0
	00 0 00000			
12432	00 0 00000		OCT	0
	00 0 00000			
12433	20 7 05367		DEC	.4938271D+17
	05 2 01171			
12434	20 0 14000	ABLE	DEC	1.0
	00 0 00000			
12435	57 7 73777		DEC	-.5
	77 7 77777			
12436	17 7 66000		DEC	.375
	00 0 00000			

12437	20 0 14000	DEC	1.0
	00 0 00000		
12440	60 0 11466	DEC	-.3995454
	73 1 10267		
12441	17 7 54455	DEC	.1434268
	71 7 14727		
12442	20 0 14000	DEC	1.0
	00 0 00000		
12443	60 0 23777	DEC	-.125
	77 7 77777		
12444	60 0 13277	DEC	-.289065
	76 5 40722		
12445	20 0 14000	DEC	1.0
	00 0 00000		
12446	17 7 64000	DEC	.250017
	10 7 23316		
12447	60 0 11400	DEC	-.40624
	05 1 74265		
12450	20 0 14000	DEC	1.0
	00 0 00000		
12451	20 0 05000	DEC	.625
	00 0 00000		

12452	17 7 26004		DEC	.023471
	31 0 11317			
12453	20 0 14000		DEC	1.0
	00 0 00000			
12454	20 0 07144		DEC	.8995
	26 4 16254			
12455	20 0 05364		DEC	.684614
	13 3 47506			
12456	20 0 14000		DEC	1.0
	00 0 00000			
12457	20 0 14000		DEC	1.0
	00 0 00000			
12460	20 0 14000		DEC	1.0
	00 0 00000			
12461	00 0 00000	DON	BSS	2
	00 0 00000			
12463	00 0 00000	TEMP	BSS	7
	00 0 00000			
12472	00 0 00000	NORM	BSS	7
	00 0 00000			
12501	00 0 00000	TTA	BSS	3
	00 0 00000			
12504	00 0 00000	TTAN	BSS	3
	00 0 00000			

12507	00 0 00000	AN	BSS	3
	00 0 00000			
12512	17 7 24357	CONV	DEC	.01745329252
	50 6 50451			
12513	00 0 00000	EBSIL	BSS	1
	00 0 00000			
12514	00 0 00000	ROB	BSS	1
	00 0 00000			
12515	00 0 00000	AXE	BSS	3
	00 0 00000			
12520	00 0 00000	COVO2	BSS	1
	00 0 00000			
12521	00 0 00000	COV24	BSS	1
	00 0 00000			
12522	00 0 00000	A24	BSS	1
	00 0 00000			
12523	00 0 00000	A242	BSS	1
	00 0 00000			
12524	00 0 00000	GET	BSS	1
	00 0 00000			
12525	00 0 00000	WIT	BSS	2
	00 0 00000			

			REM	FLOATING POINT SQUARE ROOT
12527	75 0 00000	SQRFL	SLJ 0 0	ALARM EXIT
	56 1 12552		SIU 1 SQFEXIT	STORE B1
12530	22 0 12550		AJP 0 SQFEXIT-2	TEST 0 ARGUMENT
	22 3 12527		AJP 3 SQRFL	TEST - ARGUMENT
12531	50 0 00000		ENI 0 0	
	42 0 12556		SCM 0 SQMASK1	SET CORRECT
12532	05 0 00001		ALS 0 1	SIGN FOR
	03 0 00045		LRS 0 37D	EXPONENT
12533	22 3 12534		AJP 3 /+1	COMPUTE
	11 0 00002		INA 0 2	EXPONENT
12534	11 0 03777		INA 0 3777	FOR ROOT
	03 0 00001		LRS 0 1	
12535	05 0 00044		ALS 0 36D	SHIFT EXPONENT
	20 0 12561		STA 0 SQERAS	AND SIGN
12536	44 0 12557		LDL 0 SQMASK2	
	01 0 00004		ARS 0 4	
12537	23 3 12540		QJP 3 /+1	
	01 0 00001		ARS 0 1	
12540	20 0 12562		STA 0 SQERAS+1	
	14 0 12555		ADD 0 SQFCON3	
12541	20 0 12563		STA 0 SQERAS+2	
	12 0 12554		LDA 0 SQFCON2	

12542	27 0 12563	DVF	0	SQERAS+2
	14 0 12553	ADD	0	SQFCON1
12543	50 1 00001	ENI	1 1	
	04 0 00000	ENQ	0 0	
12544	20 0 12563	STA	0	SQERAS+2
	12 0 12562	LDA	0	SQERAS+1
12545	27 0 12563	DVF	0	SQERAS+2
	14 0 12563	ADD	0	SQERAS+2
12546	01 0 00001	ARS	0 1	
	55 1 12544	IJP	1	/-2
12547	01 0 00011	ARS	0 11	
	42 0 12561	SCM	0	SQERAS
12550	32 0 12560	FMU	0	SQMASK3
	52 1 12527	LIU	1	SQRFL
12551	51 1 00001	INI	1 1	
	57 1 12552	SIL	1	/+1
12552	50 1 00000	SQFEXIT	ENI	1 0
	75 0 00000	SLJ	0 0	
12553	21 3 66405	SQFCON1	DEC	218518306D-8B45
	01 4 47436			
12554	76 3 72106	SQFCON2	DEC	-30228991714D-10B41
	43 6 47567			
12555	03 0 56173	SQFCON3	DEC	154515776D-8B43
	52 7 71341			

12556	20 0 00000	SQMASK1	OCT	2000000000000000
	00 0 00000			
12557	37 7 77777	SQMASK2	OCT	37777777777774000
	77 7 74000			
12560	20 0 14000	SQMASK3	OCT	2001400000000000
	00 0 00000			
12561	00 0 00000	SQERAS	BSS	3
	00 0 00000			

END

APPENDIX II

Solid Angle Correction

The solid angle correction, which must be applied to the theoretical correlation function to enable a comparison to be made with the experimental correlation function, is described by Rose (1). The correction involves the numerical evaluation of the integrals given by Equation (14):

$$I_{ni} = \int_0^{\gamma} P_n(\cos\theta) (1 - e^{-T_i X_i(\theta)}) \sin\theta \, d\theta$$

and the subsequent solutions of Equations (15) and (16).

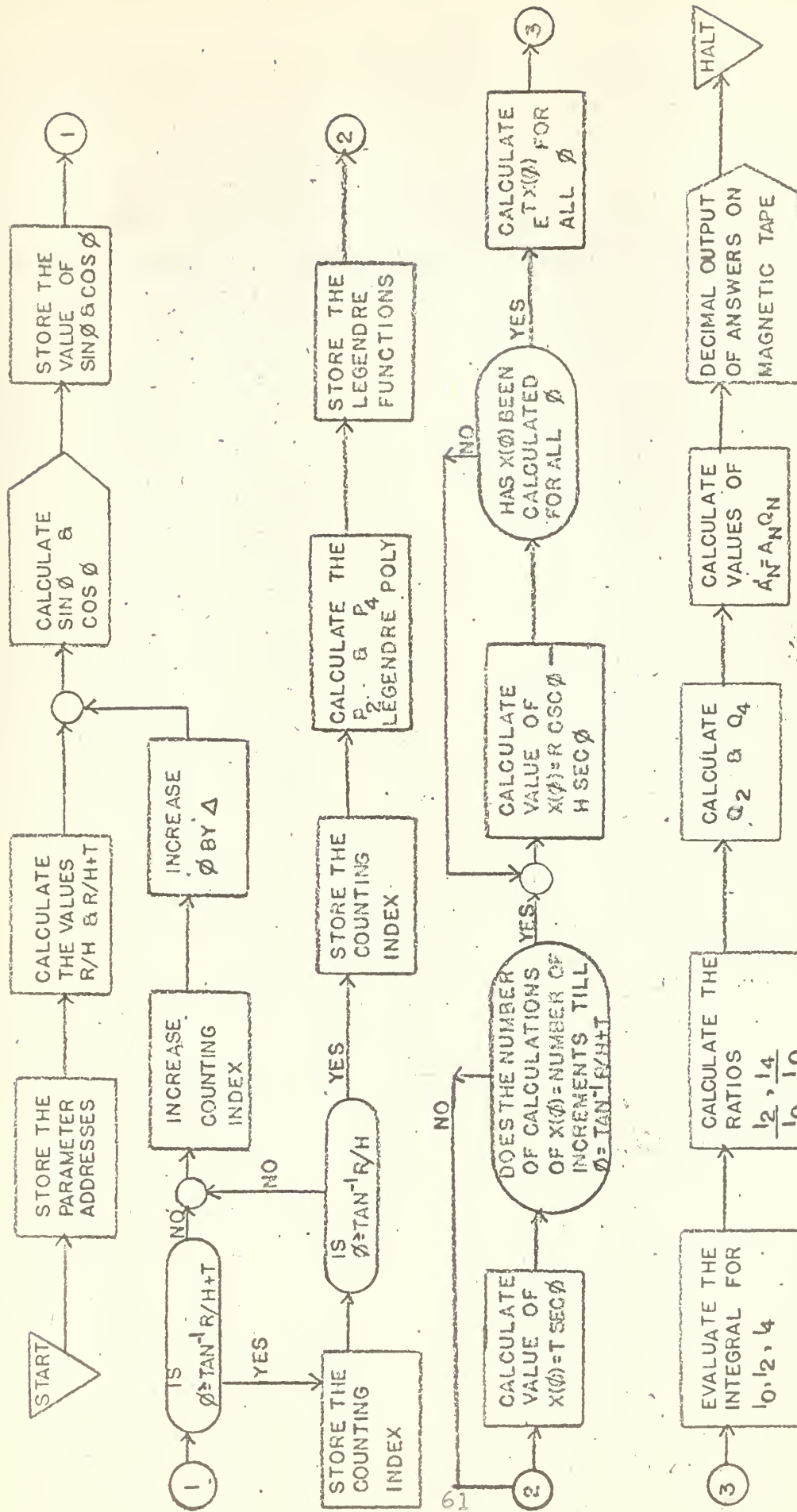
The computer solution for this correction was carried out in floating point format. The numerical integration was computed using an interval of 0.001 radians. A flow sheet outline of the program is given in Figure (8). The program must be supplied with the parameters γ , h , r , and t same in both channels (see Table 4) thus enabling solid angle corrections to be made for any experimental set-up to which these corrections may be applicable. These parameters may be placed anywhere in the computer and their addresses supplied to the program by placing them in the B registers in the following order

- B1 = r (address of the crystal radius in centimeters)
- B2 = t (address of the crystal thickness in centimeters)
- B3 = h (address of the crystal to source distance in centimeters)
- B4 = γ (the value of the full-energy absorption coefficient of the detector for the gamma ray in centimeters⁻¹)

The values of the parameters used in the calculation of the corrected angular correlation coefficients for the theoretical correlation function and the results of the calculations are listed in Table 4.

The program is available for future use on biocatal tape in machine language and on IBM cards in assembly language. The biocatal tape contains all the necessary subroutines to enable a complete computation, i.e.

1. The main program for solution of Equation (14),
2. The subroutines



SOLID ANGLE CORRECTION FLOW CHART

- a. Floating Point Sine-Cosine
- b. Floating Point Exponential
- c. Floating Point Decimal Output.

The results of the computations are dumped on magnetic tape unit (4) in the following sequence:

Line 1	I_0
Line 2	I_2
Line 3	I_4
Line 4	I_2/I_0
Line 5	I_4/I_0
Line 6	Q_2
Line 7	A_2Q_2
Line 8	Q_4
Line 9	A_4Q_4

TABLE 4
SOLID ANGLE CORRECTION PARAMETERS

h (cm)	18.0
t (cm)	2.54
r (cm)	2.54
T (cm ⁻¹)	0.098
I_0	0.0079
I_2	0.0078
I_4	0.0076
$\frac{I_2}{I_0}$	0.9882
$\frac{I_4}{I_0}$	0.9609
Q_2	0.9765
Q_4	0.9234
$Q_2 A_2$	0.0996
$Q_4 A_4$	0.0084

SOLID ANGLE CORRECTION PROGRAM

```

ORG      12000

REM      BURTON J CONWAY APRIL 1961

REM      SOLID ANGLE CORRECTIONS

REM      OF THE THEORETICAL CORRELATION

REM      CURVE.  MUST BE SUPPLIED

REM      WITH PARAMETER ADDRESSES AS

REM      FOLLOWS.

REM      B1 ADDRESS OF XTAL RADIUS.

REM      B2 ADDRESS OF XTAL THICKNESS.

REM      B3 ADDRESS OF CRYSTAL TO

REM      SOURCE DISTANCE.

REM      B4 ADDRESS OF PARAMETER TAU.

HOLD     EQU      5500

TEMP     EQU      6500

WORK2    EQU      7500

WORK4    EQU      10500

HANS     EQU      11500

SOLD     EQU      12500

JAY0     EQU      13500

JAY2     EQU      13504

JAY4     EQU      13510

JAY20    EQU      13514

```


		JAY40	EQU	13520
		EXPFL	EQU	60600
		SINFL	EQU	60000
12000	12 1 00000	LDA	1 0	
	20 0 12163	STA	0 RAD	
12001	12 2 00000	LDA	2 0	
	20 0 12164	STA	0 THK	
12002	12 3 00000	LDA	3 0	
	20 0 12165	STA	0 HGT	
12003	12 4 00000	LDA	4 0	
	20 0 12166	STA	0 TAU	
12004	12 0 12171	LDA	0 ZRO	
	20 5 13500	STA	5 JAY0	
12005	54 5 00030	ISK	5 30	
	75 0 12004	SLJ	0 /-1	
12006	12 0 12171	LDA	0 ZRO	
	20 0 12151	STA	0 DELTA	
12007	50 1 00000	ENI	1 0	
	50 2 00000	ENI	2 0	
12010	50 3 00000	ENI	3 0	
	50 4 00000	ENI	4 C	
12011	50 5 00000	ENI	5 0	
	50 6 00000	ENI	6 0	

12012	12 0 12163	START	LDA 0 RAD	FORMATION OF R/H
	33 0 12165		FDV 0 HGT	
12013	20 0 12172		STA 0 PLEAS	
	50 0 00000		ENI 0 0	
12014	12 0 12165		LDA 0 HGT	FORMATION OF R/H+T
	30 0 12164		FAD 0 THK	
12015	20 0 12175		STA 0 ONCE	
	12 0 12163		LDA 0 RAD	
12016	33 0 12175		FDV 0 ONCE	
	20 0 12175		STA 0 ONCE	
12017	12 0 12151	BGR	LDA 0 DELTA	SINE AND COSINE
	50 0 00000		ENI 0 0	FORMATION
12020	75 4 60001		SLJ 4 SINFL+1	COSINE
	50 0 00000		ENI 0 0	
12021	50 0 00000		ENI 0 0	
	50 0 00000		ENI 0 0	
12022	50 0 00000		ENI 0 0	
	50 0 00000		ENI 0 0	
12023	20 1 06500		STA 1 TEMP	COSINE TO RADIANS
	12 0 12151		LDA 0 DELTA	
12024	75 4 60000		SLJ 4 SINFL	SINE FACTOR
	50 0 00000		ENI 0 0	
12025	50 0 00000		ENI 0 0	
	50 0 00000		ENI 0 0	

12026	50 0 00000		ENI 0 0	
	50 0 00000		ENI 0 0	
12027	20 1 05500		STA 1 HOLD	SINE TO STORAGE
	33 1 06500		FDV 1 TEMP	SINE/COSINE
12030	31 0 12175	REPL	FSB 0 ONCE	SINE/COSINE-R/H+T
	22 0 12141		AJP 0 FIRST	JUMPS IF A IS 0
12031	22 2 12141		AJP 2 FIRST	JUMPS IF A IS +
	51 1 00001		INI 1 1	
12032	12 0 12152		LDA 0 DELTA+1	
	30 0 12151		FAD 0 DELTA	
12033	20 0 12151		STA 0 DELTA	
	75 0 12017		SLJ 0 BGN	
12034	56 1 12105	NEXT	SIU 1 JAY+3	STARTS FORMATION OF
	56 1 12073		SIU 1 INCL+5	THE LEGENDRE POL.
12035	56 1 12111		SIU 1 JAYTO+3	
	56 1 12051		SIU 1 RMK	
12036	56 1 12074		SIU 1 INCL+6	
	56 1 12101		SIU 1 JAY-1	
12037	56 1 12115		SIU 1 JAYFR+3	
	50 1 00000		ENI 1 0	
12040	12 1 06500		LDA 1 TEMP	COSB IN A REG.
	32 1 06500		FMU 1 TEMP	

12041	20 0 12173		STA 0 DON	
	32 0 12157		FMU 0 FLT2	
12042	31 0 12155		FSB 0 FLT	
	33 0 12156		FDV 0 FLT1	P2 IN A REG.
12043	20 1 07500		STA 1 WORK2	
	12 0 12173		LDA 0 DON	
12044	32 0 12161		FMU 0 FLT ⁴	
	20 0 12174		STA 0 DON+1	
12045	12 0 12173		LDA 0 DON	
	32 0 12173		FMU 0 DON	
12046	32 0 12162		FMU 0 FLT5	
	31 0 12174		FSB 0 DON+1	
12047	30 0 12157		FAD 0 FLT2	P ⁴ IN THE A REG.
	33 0 12160		FDV 0 FLT3	
12050	20 1 10500		STA 1 WORK4	
	50 0 00000		ENI 0 0	
12051	54 1 00000	RMK	ISK 1 0	NUMBER OF ANGLES
	75 0 12040		SLJ 0 NEXT+4	INSERTED BY PROGRAM
12052	12 0 12164	HALF	LDA 0 THK	FORMATION OF XB
	33 1 06500		FDV 1 TEMP	
12053	20 1 11500		STA 1 HANS	
	50 0 00000		ENI 0 0	
12054	54 1 00000		ISK 1 0	NUMBER INSERTED
	75 0 12052		SLJ 0 HALF	BY PROGRAM

12055	12 1 11500		LDA 1 HANS	
	32 0 12166		FMU 0 TAU	
12056	20 1 11500		STA 1 HANS	
	50 0 00000		ENI 0 0	
12057	54 1 00000		ISK 1 0	NUMBER ENTERED
	75 0 12055		SLJ 0 /-2	BY PROGRAM
12060	12 1 11500	POWER	LDA 1 HANS	STARTS FORMATION
	75 4 60600		SLJ 4 EXPFL	OF E TO THE TAU X
12061	50 0 00000		ENI 0 0	
	50 0 00000		ENI 0 0	
12062	20 1 12500		STA 1 SOLD	
	50 0 00000		ENI 0 0	
12063	54 1 00000		ISK 1 0	
	75 0 12060		SLJ 0 POWER	
12064	54 2 00001		ISK 2 1	
	75 0 12066		SLJ 0 /+2	
12065	75 0 12076		SLJ 0 HANG	
	50 0 00000		ENI 0 0	
12066	50 1 00000	INCL	ENI 1 0	
	51 1 00001		INI 1 1	
12067	12 0 12165		LDA 0 HGT	STARTS CALCULATION
	33 1 06500		FDV 1 TEMP	R CSCB-SECB

12070	20 1 12500		STA 1 SOLD	
	12 0 12163		LDA 0 RAD	
12071	33 1 05500		FDV 1 HOLD	
	31 1 12500		FSB 1 SOLD	
12072	32 0 12166		FMU 0 TAU	
	20 1 11500		STA 1 HANS	
12073	54 1 00000		ISK 1 0	
	75 0 12067		SLJ 0 /-4	
12074	50 1 00000		ENI 1 0	
	56 1 12063		SIU 1 POWER+3	
12075	50 1 00000		ENI 1 0	
	75 0 12060		SLJ 0 POWER	
12076	12 0 12155	HANG	LDA 0 FLT	
	33 1 12500		FDV 1 SOLD	
12077	20 1 12500		STA 1 SOLD	
	12 0 12155		LDA 0 FLT	
12100	31 1 12500		FSB 1 SOLD	
	20 1 12500		STA 1 SOLD	
12101	54 1 00000		ISK 1 0	
	75 0 12076		SLJ 0 HANG	
12102	12 0 12153	JAY	LDA 0 WORK	STARTS CALCULATION
	32 1 12500		FMU 1 SOLD	OF THE INTERGAL
12103	32 1 05500		FMU 1 HOLD	
	32 0 12152		FMU 0 DELTA+1	

12104	30 0 13500		FAD 0 JAY0	
	20 0 13500		STA 0 JAY0	
12105	54 1 00000		ISK 1 0	
	75 0 12102		SLJ 0 /-3	
12106	12 1 07500	JAYTO	LDA 1 WORK2	
	32 1 12500		FMU 1 SOLD	
12107	32 1 05500		FMU 1 HOLD	
	32 0 12152		FMU 0 DELTA+1	
12110	30 0 13504		FAD 0 JAY2	
	20 0 13504		STA 0 JAY2	
12111	54 1 00000		ISK 1 0	NUMBER OF TIMES
	75 0 12106		SLJ 0 /-3	TILL R/H
12112	12 1 10500	JAYFR	LDA 1 WORK4	
	32 1 12500		FMU 1 SOLD	
12113	32 1 05500		FMU 1 HOLD	
	32 0 12152		FMU 0 DELTA+1	
12114	30 0 13510		FAD 0 JAY4	
	20 0 13510		STA 0 JAY4	
12115	54 1 00000		ISK 1 0	NUMBER OF TIMES
	75 0 12112		SLJ 0 /-3	TILL R/H
12116	12 0 13504		LDA 0 JAY2	
	33 0 13500		FDV 0 JAY0	

12117	20 0 13514	STA 0 JAY20
	12 0 13510	LDA 0 JAY4
12120	33 0 13500	FDV 0 JAY0
	20 0 13520	STA 0 JAY40
12121	12 0 13514	LDA 0 JAY20
	32 0 13514	FMU 0 JAY20
12122	20 0 13524	STA 0 JAY40+4
	32 0 12167	FMU 0 THEOR
12123	20 0 13530	STA 0 JAY40+10
	12 0 13520	LDA 0 JAY40
12124	32 0 13520	FMU 0 JAY40
	20 0 13534	STA 0 JAY40+14
12125	32 0 12170	FMU 0 THEOR+1
	20 0 13540	STA 0 JAY40+20
12126	54 1 77777	ISK 1 77777
	75 0 12126	SLJ 0 /
12127	50 0 00000	ENI 0 0
	74 7 42040	EXF 7 42040
12130	75 4 71000	SLJ 4 71000
	50 0 00000	ENI 0 0
12131	01 0 13500	01 0 JAY0
	04 0 00001	04 0 1
12132	12 0 12154	LDA 0 MIKE
	70 0 12131	RAD 0 /-1

12133	54 5 00010	ISK 5 10	
	75 0 12130	SLJ 0 /-3	
12134	54 1 77777	ISK 1 77777	
	75 0 12134	SLJ 0 /	
12135	54 2 77777	ISK 2 77777	
	75 0 12135	SLJ 0 /	
12136	50 0 00000	ENI 0 0	
	74 7 42040	EXF 7 42040	
12137	74 0 42003	EXF 0 42003	
	50 0 00000	ENI 0 0	
12140	76 0 05000	SLS 0 5000	
	50 0 00000	ENI 0 0	
12141	12 0 12147	FIRST LDA 0 SEC	MODIFIES THE PROGRAM
	20 0 12030	STA 0 REPL	WHEN THE VALUE OF
12142	12 0 12150	LDA 0 SEC+1	B CHANGES
	20 0 12031	STA 0 REPL+1	
12143	56 1 12054	SIU 1 HALF+2	
	56 1 12057	SIU 1 HALF+5	
12144	56 1 12063	SIU 1 POWER+3	
	56 1 12075	SIU 1 INCL+7	
12145	56 1 12066	SIU 1 INCL	
	51 1 00001	INI 1 1	

12146	75 0 12017		SLJ	0 BGN	
	50 0 00000		ENI	0 0	
12147	31 0 12172	SEC	FSB	0 PLEAS	PARAMETER TO MODIFY
	22 0 12034		AJP	0 NEXT	PROGRAM FOR B
12150	22 2 12034		AJP	2 NEXT	GREATER THAN R/H+T
	51 1 00001		INI	1 1	
12151	00 0 00000	DELTA	OCT	0	
	00 0 00000				
12152	17 6 64061		DEC	.001	
	11 5 64570				
12153	20 0 14000	WORK	DEC	1.0	
	00 0 00000				
12154	00 0 00004	MIKE		0 0 4	
	00 0 00001			0 0 1	
12155	20 0 14000	FLT	DEC	1.0	
	00 0 00000				
12156	20 0 24000	FLT1	DEC	2.0	
	00 0 00000				
12157	20 0 26000	FLT2	DEC	3.0	
	00 0 00000				
12160	20 0 44000	FLT3	DEC	8.0	
	00 0 00000				
12161	20 0 57400	FLT4	DEC	30.0	
	00 0 00000				

12162	20 0 64300	FLT5	DEC	35.0
	00 0 00000			
12163	20 0 25050	RAD	DEC	2.54
	75 3 41217			
12164	20 0 25050	THK	DEC	2.54
	75 3 41217			
12165	20 0 54400	HGT	DEC	18.0
	00 0 00000			
12166	17 7 46213	TAU	DEC	.098
	20 7 12601			
12167	17 7 46416	THEOR	DEC	.1020
	25 4 02030			
12170	17 7 14511		DEC	.00907
	51 2 62577			
12171	00 0 00000	ZRO	OCT	0
	00 0 00000			
12172	00 0 00000	PLEAS	BSS	1
	00 0 00000			
12173	00 0 00000	DON	BSS	2
	00 0 00000			
12175	00 0 00000	ONCE	BSS	1
	00 0 00000			

END

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Gamma-gamma angular correlation in the d



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